CWE-8
June 7-11, 2026
London, ON, Canada

Large-Eddy Simulations of Pressure Driven Interior Flows

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SUMMARY

Airflow network models are widely utilized in building energy modelling to predict natural ventilation and cooling capacity. These models can predict ventilation rates within 10% of coupled indoor-outdoor LES results when prescribed accurate pressure coefficients. However, natural cooling also depends on the interior flow patterns that influence convective cooling of building surfaces. The objective of this work is to compare interior flow field predictions obtained using an indoor LES model with prescribed velocities and pressures at windows to predictions obtained with a coupled indoor-outdoor model. Four room types (single sided, corner, dual-room, and cross ventilation) are considered under varying wind directions and urban canopy conditions. Indoor flow patterns, ventilation rates, and wall heat fluxes from the indoor-only model are compared to the coupled model. Ultimately, these results will inform training of a machine learning model to predict interior flow fields across diverse room layouts, window configurations, and outdoor flow conditions.

Keywords: *Natural Ventilation, Large Eddy Simulation, Interior Flow*

1. INTRODUCTION

Building energy consumption constitutes a major share of global energy demand, accounting for approximately 36% of total energy use worldwide, largely concentrated in urban areas (Zarco-Soto et. al, 2025). This figure is projected to increase as urban areas continue to grow and global populations increase. Thus, there is a need to reduce building energy consumption to safeguard global electrical infrastructure. Natural cooling (NC) is a promising solution, as it can reduce or even eliminate the use of mechanical cooling systems. Nighttime cooling leverages wind and buoyant forces alongside thermal storage to expel indoor heat in the evening when outdoor temperatures drop and maintain comfortable building temperatures the next day. This cooling strategy can be very effective, but there is a lack of comprehensive design tools that can accurately predict natural cooling across diverse building configurations and built environments.

Predicting natural cooling requires accurate predictions of ventilation flow rates and heat transfer coefficients. Ventilation rates are typically obtained from airflow network models that require inputs for the pressures at building openings. The pressure values are typically sourced from empirical data based on wind tunnel experiments that were performed for the flow around isolated building shapes. Corrections can be specified to account for changes in the flow due to the surrounding canopy. However, it has been shown that these simplified corrections cannot accurately reflect the complexity of the flow behavior within urban canopies and that significant errors can arise in pressure values, and thus, ventilation predictions (Bachand et al., 2025a). In ongoing work, the use of Neural Networks (NNs) to obtain accurate pressure predictions on a variety of building designs in a variety of urban canopy geometries is being explored (Bachand et al., 2025b). The heat transfer coefficients are typically also specified based on limited empirical data, and significant errors can arise depending on the room configuration and indoor flow patterns (Wai et al., 2025).

The goal of this work is to explore the development of surrogate models that can more accurately predict indoor flow patterns and the resulting heat transfer coefficients. This abstract considers the first step of this work, where the objective is to determine the accuracy of indoor flow and heat transfer coefficient predictions obtained from an LES model that only solves for the indoor airflow based on pressure boundary conditions at the openings. To achieve this objective, we consider the configurations considered in a previous study by Bachand and Gorlé (2025a), where LES of the coupled indoor-outdoor flow were performed. The study considered simplified homes comprised of rooms with four ventilation configurations: single-sided, corner, dual-room, and cross ventilation. In addition, different canopy densities, wind directions, and house locations within the urban canopy were analyzed. To perform the LESs for the indoor flow only we extract velocity and pressure boundary conditions from another set of LESs performed for the outdoor flow only (Bachand et al., 2025b). We compare the resulting interior flow patterns, flow rates, and heat transfer coefficients across the different wind directions and house locations. The results will be used to inform the future development of surrogate models for indoor flow patterns and heat transfer coefficients.

2. METHODOLOGY

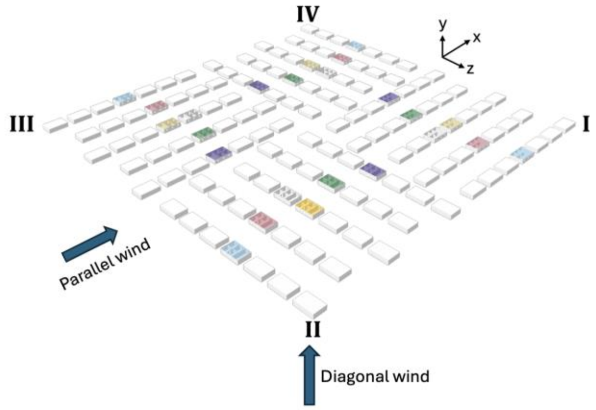
The following section summarizes the solver used, the databases for the coupled indoor-outdoor airflow and for the pressures on the window openings, and the indoor airflow only simulations.

2.1. Large-eddy simulations

The simulations are performed using the low-Mach formulation of the CharLES code developed by Cadence Design Systems. CharLES is a finite volume solver with a body-fitted meshing technique based on 3D clipped Voronoi diagrams. The low-Mach formulation solves the filtered equations for conservation of mass and momentum with the density approximated as the sum of a background density and an isentropic, acoustic perturbation. The Vreman model is used to represent the subgrid scales.

2.2. Databases for coupled indoor-outdoor airflow and window pressures

The previous simulations of the coupled indoor-outdoor airflow considered two computational domains with different canopy densities. Fig. 1 (left) shows the layout of the high-density canopy. The domain includes four rotated canopy quadrants with 35 buildings each (Bachand et al., 2025). Simulations were performed for parallel and diagonal wind. Within each quadrant, the indoor flow within six of the houses, indicated with colors in Fig. 1, was resolved. Fig. 1 (right) shows the interior house layout, which was designed to represent ventilation for different room types and window placements. The ventilation configurations are referred to as single-sided, dual room, corner, and cross ventilation. Most rooms are square shaped, with a length of LR = 4m and extruded upwards to a height of HR = 3m, except for the cross ventilated room, which has a length of 2LR. All windows are square shaped and placed in the center of the room walls with lengths of HR/4 The datasets produced from the simulations include ventilation rates, mean flow patterns within the rooms, and heat transfer coefficients (Bachand et al., 2025b). In a follow-up study, simulations of the outdoor flow were only performed to extract pressure coefficients on the window openings. These pressure values were used within an airflow network model, which showed good agreement with the LES ventilation rates. In the current study, these same pressure values, as well as additional information on the outdoor wind speed and direction, will be used to perform LES of the interior flows patterns only and compare the results to the interior flow patterns obtained from the coupled indoor-outdoor simulations.



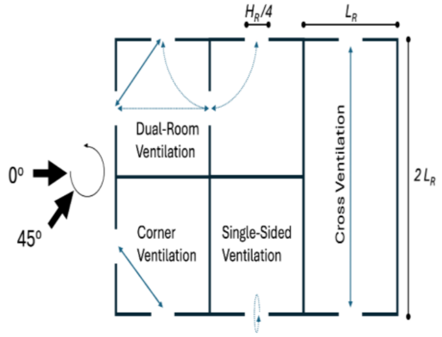


Fig 1: Left: urban canopy layout used for the coupled indoor-outdoor coupled simulations. Fig 2: Right: Diagram of the interiors with four ventilation configurations (Bachand et al.,2025).

2.3. Indoor flow simulations

The computational domain for the indoor flow simulations only considers the different rooms represented in Figure 2. On the wall surfaces a standard algebraic smooth wall model is used. In the first iteration of the simulations presented in this abstract, the flow is driven by specifying pressures at the window openings, corresponding to the pressures obtained from the database described in Section 2.2. A total gauge pressure condition is imposed on the modeled windows with a relaxation time parameter associated with the acoustic travel time across the domain. In future simulations, we will include information on the wind speed and wind direction to account for the effect of the outdoor wind field on the indoor flow field.

3. PRELIMINARY RESULTS

Initial simulations have been run for the cross and corner ventilated rooms under the same inlet gauge pressure of 15Pa. The resulting velocity fields are presented in Fig 3. For the cross ventilated case there is straight flow path from the inlet to the outlet window, and velocities up to 5m/s are observed. For the corner ventilation case, there is no straight flow path between the inlet and outlet windows, and the velocities are significantly lower than for the cross-ventilated case. These flow fields will change significantly depending on the outdoor wind speed and wind direction, in particular when the flow near the inlet window becomes more or less aligned with the direct flow path between the inlet and outlet windows. Future simulations will use more advanced boundary conditions to represent these effects.

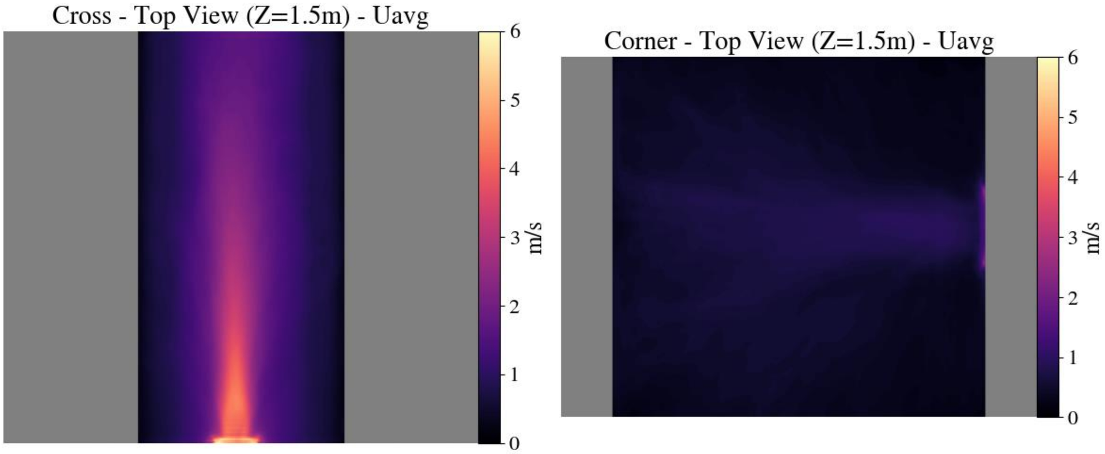


Fig 3: Internal flow results for the cross ventilated room (Left) and corner ventilated room (Right)

4. CONCLUSIONS AND FUTURE WORK

In ongoing work, we are exploring more advanced boundary conditions that can account for the effects of the outdoor wind field. We will perform simulations of the indoor air flow across all room geometries, for the different wind directions, the different canopy densities, and the different house locations within the canopy. Using these simulations, we will quantify the differences in interior flow behavior, ventilation rates, and heat transfer coefficients between the pressure driven indoor-only LES model and the coupled indoor-outdoor airflow LES model. This comparison will inform future development of fast reduced order models for predicting indoor ventilation patterns and heat transfer coefficients.

ACKNOWLEDGEMENTS

Computing for this project was performed on the Sherlock cluster. We would like to thank Stanford University and the Stanford Research Computing Center for providing computational resources and support that contributed to these research results.

References

F. J. Zarco-Soto, I. M. Zarco-Soto, S. S. S. Ali, and P. J. Zarco-Periñán, "Energy consumption in buildings: A compilation of current studies," Energy Reports, vol. 13, pp. 1293–1307, 2025, doi: 10.1016/j.egyr.2024.12.069.

L. W. Chew, C. Chen, and C. Gorlé, "Improving thermal model predictions for naturally ventilated buildings using large eddy simulations," *Building and Environment*, vol. 220, p. 109241, 2022, doi: 10.1016/j.buildenv.2022.109241.

N. Bachand, H. Salehipour, and C. Gorle, "Simulating The Urban Canopy's Impact on Wind-Driven Natural Ventilation and Cooling," 2025a, arXiv: arXiv:2508.04091. doi: 10.48550/arXiv.2508.04091.

N. G. Bachand, T. Vargiemezis, and C. Gorle, "Combining LES, Machine Learning, and Reduced-Order Models for Predicting Natural Ventilation," Division of Fluid Dynamics Annual Meeting 2025b, Nov. 2025. https://archive.aps.org/dfd/2025/k10/1/

T. Vargiemezis and C. Gorlé, "From large-eddy simulations to deep learning: A U-net model for fast urban canopy flow predictions," Sustainable Cities and Society, vol. 135, p. 107005, Dec. 2025, doi: 10.1016/j.scs.2025.107005.